Studying the Origin of Kuroshio with an Array of ADCP-CTD Moorings

Ren-Chieh Lien
Applied Physics Laboratory
University of Washington
1013 NE 40th Street
Seattle, Washington 98105
Phone: (206) 685-1079 fax: (206) 543-6785 email: lien@apl.washington.edu

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LONG-TERM GOALS

Our long-term scientific goals are to understand the dynamics and identify mechanisms of small-scale processes—i.e., internal tides, inertial waves, nonlinear internal waves (NLIWs), and turbulence mixing—in the ocean and their interaction with mesoscale processes such as western boundary currents. We aim to develop improved parameterizations of mixing for ocean models. For this study, our focus is on the origin of the Kuroshio, the interaction among internal tides, internal waves, mesoscale eddies, and the Kuroshio, and the interaction of oceanic processes with the complex topography in Luzon Strait.

OBJECTIVES

The primary objectives of this observational program are to quantify the origin of the Kuroshio and to quantify its properties at the origin and as it evolves downstream.

APPROACH

An array of six subsurface moorings is deployed northeast of the Philippines, where the strong Kuroshio enters Luzon Strait. Each mooring has an Acoustic Doppler Current Profiler (ADCP) to measure the velocity field in the upper 600 m. Our long-term velocity observations and complementary shipboard survey will help identify the origin of the Kuroshio and its properties before it enters Luzon Strait. We will compare our observations with glider and HPIES observations and with downstream mooring observations east of Taiwan to quantify the evolution of the Kuroshio.

WORK COMPLETED

In FY12 we attended one ONR workshop in Taiwan in April 2012. The observation plan was presented.

We conducted the RR-1205 R/V *Revelle* cruise (6/3 – 6/16 2012) northeast of the Philippines (Luzon Strait) during which we deployed moorings and HPIES, and performed shipboard conductivity-temperature-depth (CTD) and ADCP observations and a bathymetry survey. Six subsurface ADCP

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moorings were deployed along 18.75°N on a progressively deepening slope; the shallowest mooring (M1) was deployed at 980-m depth and the deepest mooring (M6) at 4,465-m depth with ~8.5 n mi separation (Fig. 1). The mooring array location was determined from the analysis result of previous velocity observations of shipboard ADCP and surface drifters, and from the shipboard survey during the RR-1205 cruise where the maximum meridional velocity of the Kuroshio current was centered. Each mooring was equipped with one upward looking 75-kHz ADCP at 450-m depth. The ADCP pings every 90 sec, producing an ensemble average every 15 min. Sixty-one CTD casts were made during the cruise (Fig. 2).

RESULTS

RR-1205 CTD Casts

The temperature-salinity (T-S) diagram from the RR-1205 shipboard CTD as well as historical data from *Taiwan National Ocean Data Bank* are shown in Fig. 3. The Kuroshio has distinct T-S properties. The T-S properties in the downstream Kuroshio (Fig. 3, right panel; black dots) suggests that the warm and salty upstream Kuroshio (Fig. 3, right panel; blue and green dots) was modified when it traveled and looped around Luzon Strait and the southern tip of Taiwan, where it may have mixed with South China Sea (SCS) water and/or western Pacific water.

Ten repeated hydrographic cross-sections were generated from the CTD transects along 18.8°N. The characteristics of North Pacific Tropical Water (NPTW) with a salinity maximum (> 34.8 psu) at 100–200-m depth and North Pacific Intermediate Water (NPIW) with a salinity minimum (~ 34.2 psu) at 500–600-m depth were evident (Fig. 4). The isopycnal tilt is consistent with the geostrophic balance of the Kuroshio. The isopycnal levels off at ~550-m depth, indicating the maximum vertical extent of the Kuroshio.

RR-1205 Shipboard ADCP

The cross-sections along 18.8°N from the shipboard 75-kHz ADCP during the CTD transects measured the strong northward flow of the Kuroshio current (Fig. 5). The persistent meridional flow (> 0.8 m/s) was observed in the upper 300 m. The strength and position of the maximum northward current had significant variability over the 10-day observational period, suggesting the combination of the Kuroshio current with internal tides, eddies, and other oceanic processes.

IMPACT/APPLICATION

The Kuroshio is well defined north of Luzon Strait as a strong western boundary current. Nonetheless, its origin and the dynamics of its initiation are not well understood. The potential origin of the Kuroshio is complicated by a rich spectrum of oceanic processes, e.g., remotely and locally generated eddies. The Kuroshio carries significant mass, heat, and energy from the tropics to the subtropics and interacts with marginal seas. Therefore it is crucial to understand its origin and dynamics.

RELATED PROJECTS

Energy Budget of Nonlinear Internal Waves near Dongsha (N00014-05-1-0284) as a part of NLIWI DRI: In this project, we study the dynamics and quantify the energy budget of nonlinear internal waves (NLIWs) in the South China Sea using observations taken from two intensive shipboard experiments in

2005 and 2007 and a set of nearly one-year velocity-profile measurements taken in 2006–2007 from three bottom-mounted ADCPs across the continental slope east of Dongsha Plateau in the South China Sea. Results of the NLIWI DRI help improve our understanding of the dynamics of NLIWs and apply to the present project.

Study of Kuroshio Intrusion and Transport Using Moorings, HPIES, and EM-APEX Floats (N00014-08-1-0558) as a part of QPE DRI: The primary objectives of this observational program are 1) to quantify and to understand the dynamics of the Kuroshio intrusion and its migration into the southern East China Sea (SECS), 2) to identify the generation mechanisms of the Cold Dome often found on the SECS, 3) to quantify the internal tidal energy flux and budgets on the SECS and study the effects of the Kuroshio front on the internal tidal energy flux, 4) to quantify NLIWs and provide statistical properties of NLIWs in the SECS, and 5) to provide our results to acoustic investigators to assess the uncertainty in acoustic predictions. Results of the QPE DRI will provide a better understanding of the dynamics of NLIWs and internal tides that have strong effects on acoustic propagation and sonar performance.

Process Study of Oceanic Responses to Typhoons Using Arrays of EM-APEX Floats and Moorings (N00014-08-1-0560) as a part of ITOP DRI: We study the dynamics of the oceanic response to and recovery from tropical cyclones in the western Pacific using long-term mooring observations and an array of EM-APEX floats. Pacific typhoons may cause cold pools on the continental shelf of the East China Sea. The cold pool dynamics are likely related to the Kuroshio and its intrusion as well as to shelf/slope oceanic processes.

PUBLICATIONS

Rudnick, D.L., S. Jan, L. Centurioni, C.M. Lee, R.-C. Lien, J. Wang, D.-K. Lee, R.-S. Tseng, Y.Y. Kim, and C.-S. Chern. 2011. Seasonal and mesoscale variability of the Kuroshio near its origin. *Oceanography* **24**(4):52–63, http://dx.doi.org/10.5670/oceanog.2011.94 . [refereed]

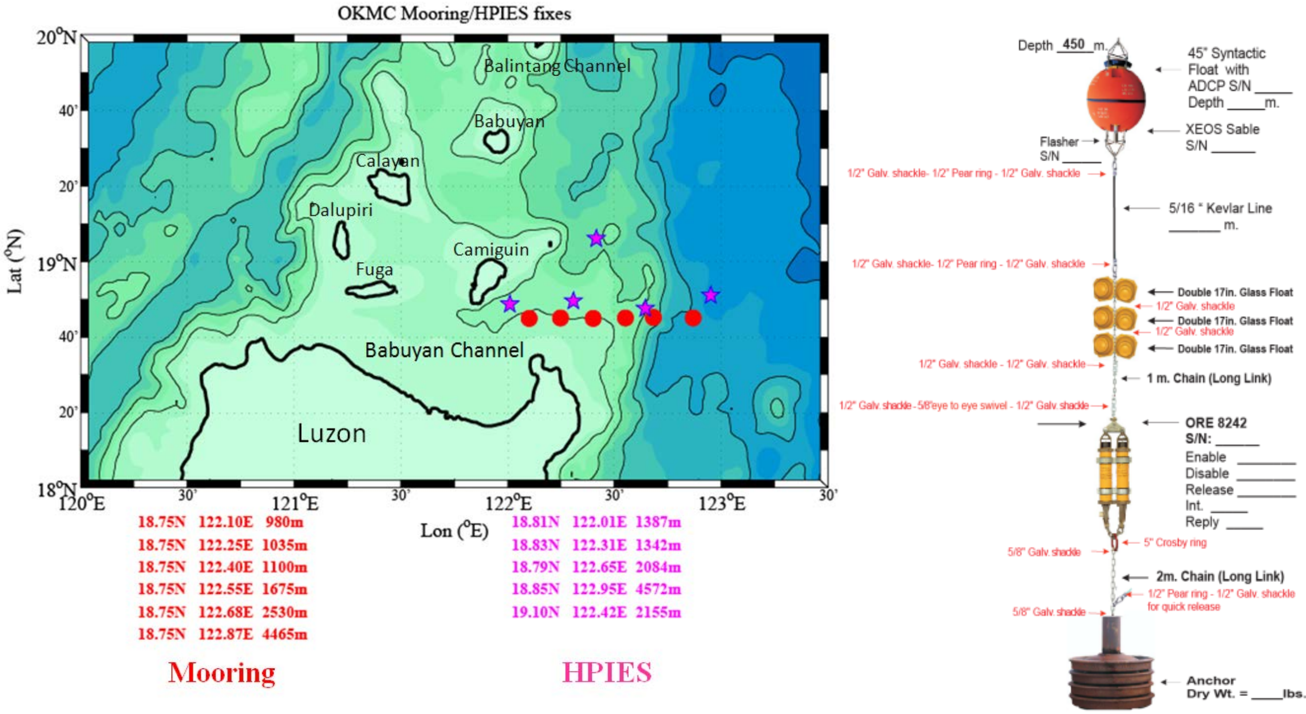

Figure 1. Positions of ADCP moorings (red dots) and HPIES (magenta stars) (left panel), and the ADCP mooring configuration (right panel). The mooring is equipped with one upward looking 75-kHz ADCP at 450-m depth.

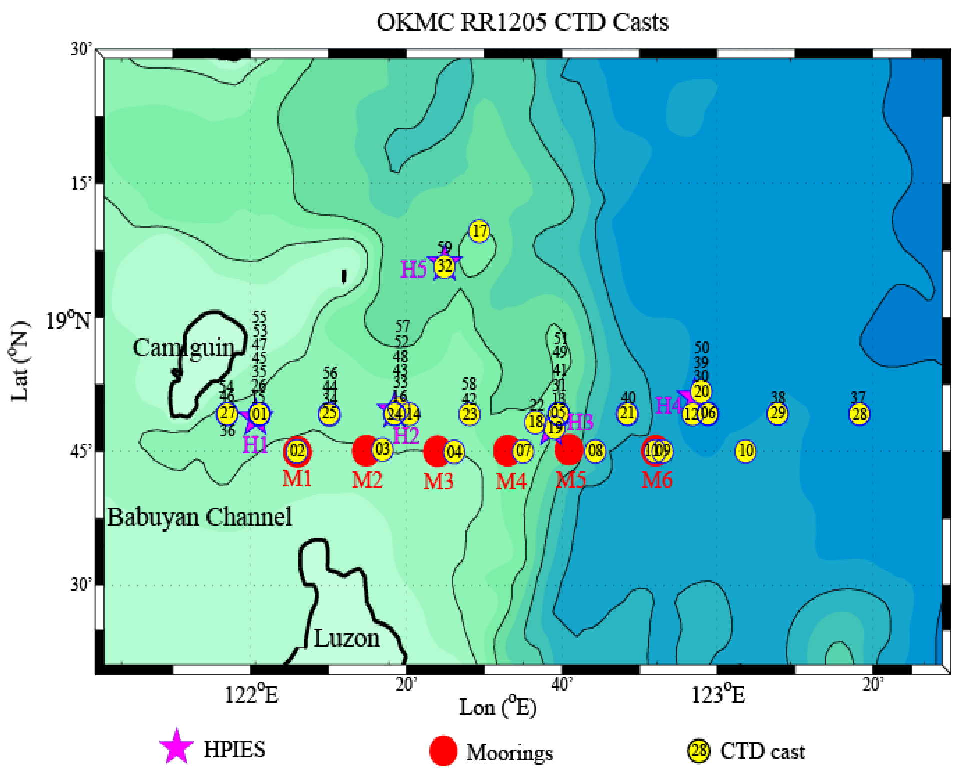

Figure 2. RR-1205 CTD stations (filled yellow circles) and cast numbers. Fifty-nine stations and sixty-one casts were made during the cruise. The positions of six moorings M1-M6 (red dots), and 5 HPIES H1-H5 (magenta stars) are labeled.

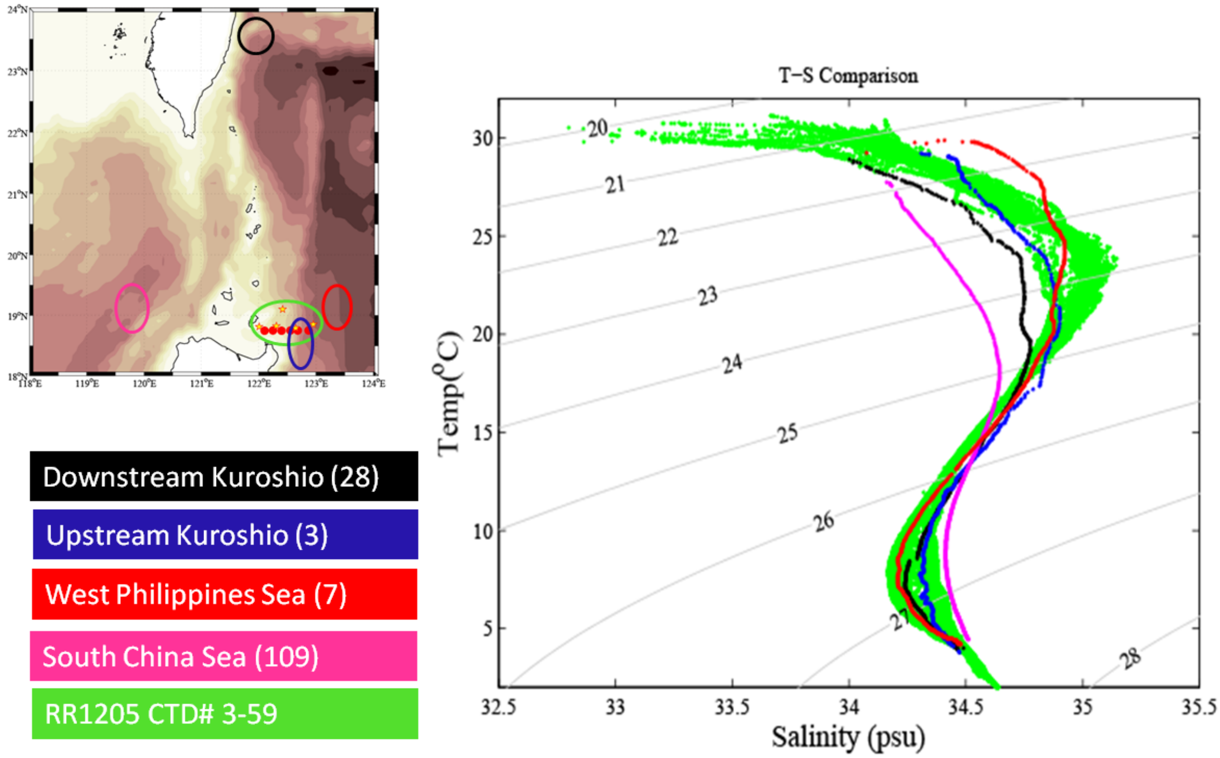

Figure 3. The temperature-salinity (T-S) property comparison of RR-1205 CTD casts with historical data in adjacent seas. The color circles on the left panel show the locations of the T-S profiles. The numbers in brackets represent the number of profiles averaged in each region. The right panel shows the T-S observations in the downstream Kuroshio (black dots), upstream Kuroshio (blue dots)and west Philippines Sea (red dots) provided by the Taiwan National Ocean Data Bank. The T-S observations taken in RR-1205 CTD are shown as green dots. The T-S observations in South China Sea water are shown as magenta dots. The labeled background curves are the density contours.

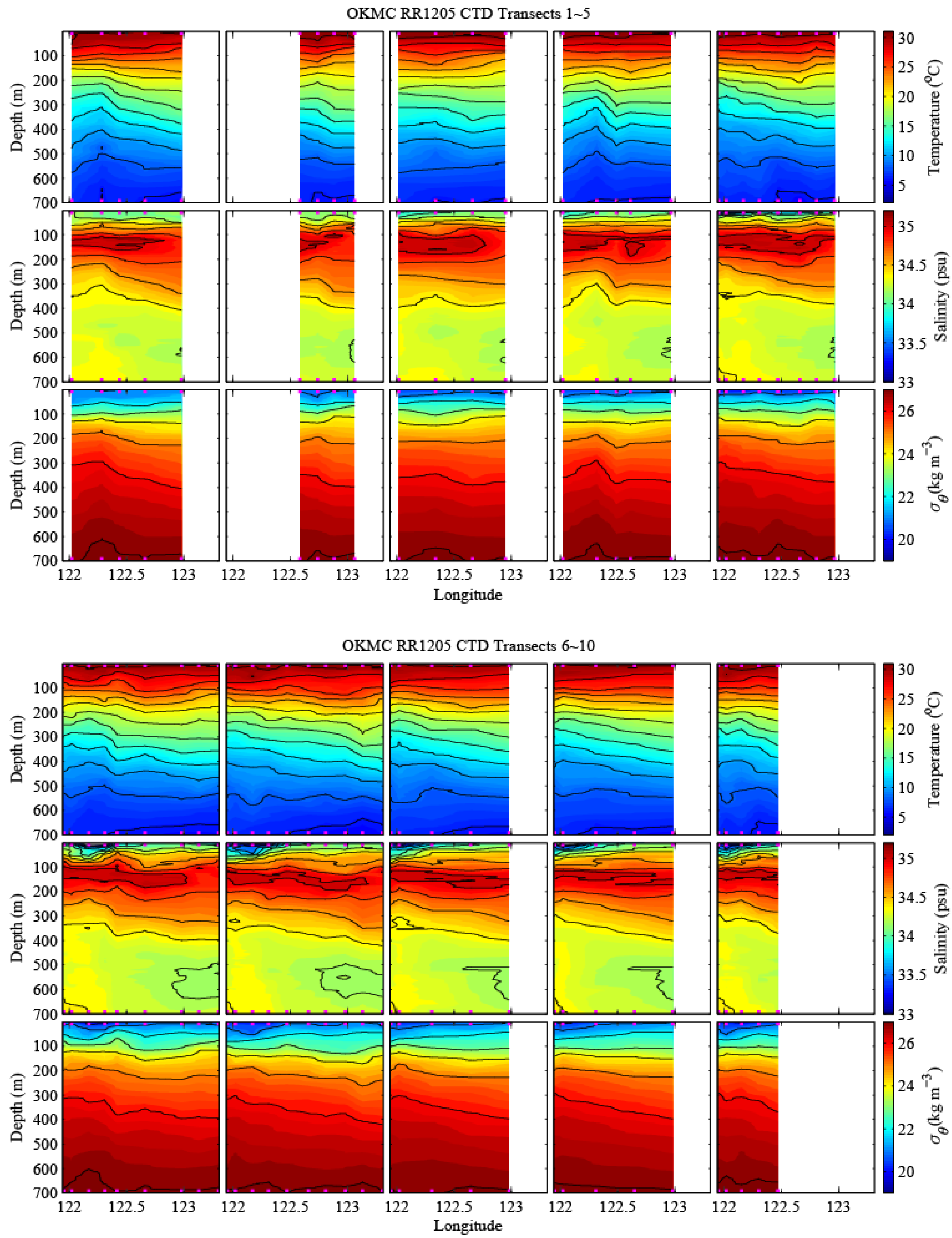

Figure 4. Ten cross-sections of temperature, salinity, and density contours derived from 61 CTD casts. North Pacific Tropical Water with a salinity maximum (> 34.8 psu) at 100–200 m and North Pacific Intermediate Water with a salinity minimum (~ 34.2 psu) at 500–600m were observed (middle panel on each transect).

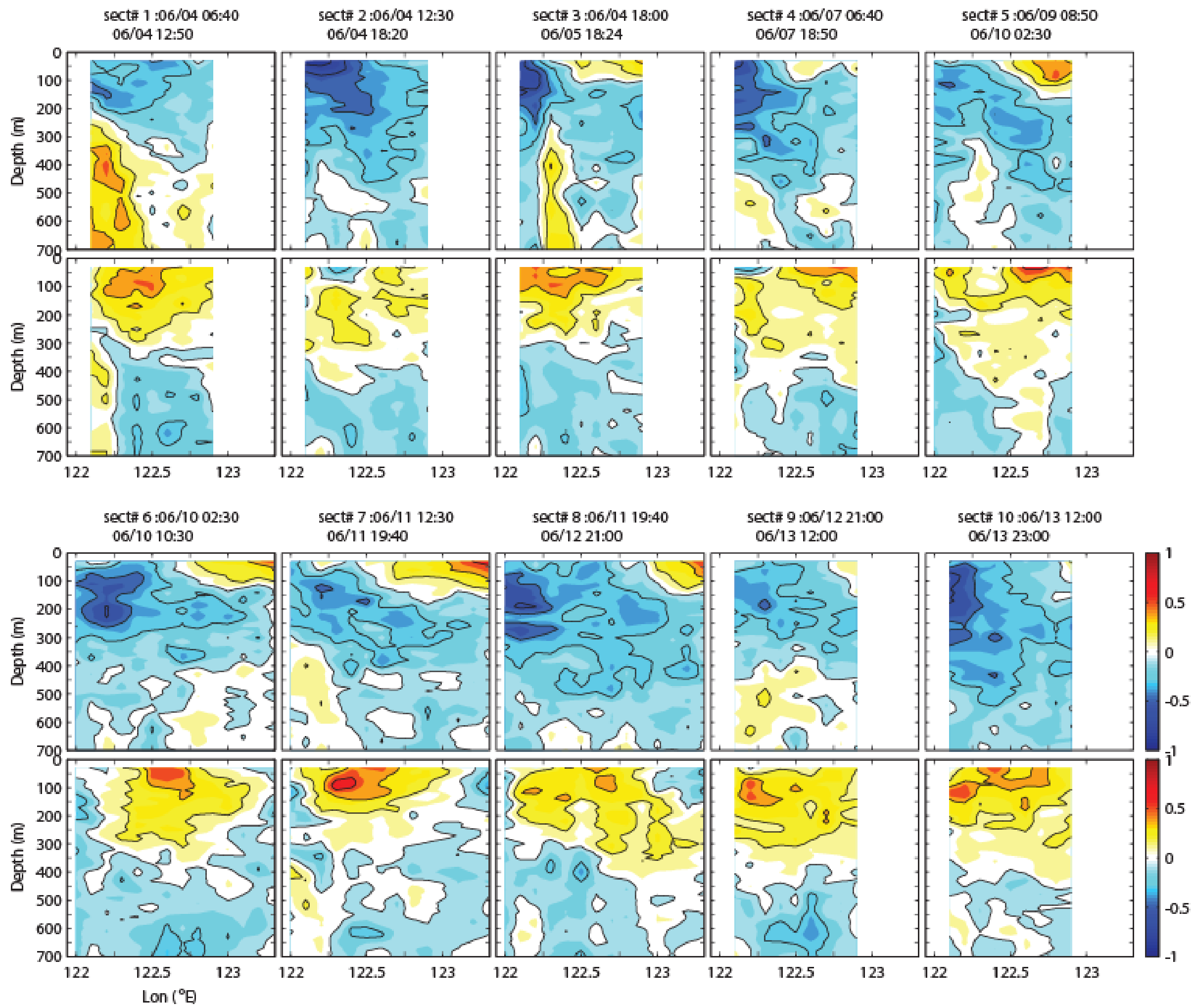

Figure 5. Ten cross-sections of meridional (second and fourth rows) and zonal velocities (first and third rows) from a 75-kHz shipboard ADCP during the CTD transects. The meridional velocity maximum, a suggestion of the Kuroshio current (mixed with other oceanic processes), is centered at ~122.5°E.